Influence of Hydrological Variables on Macrophytes in a Black Water River Ecosystem

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ABSTRACT: This study assessed the influence of hydrological variables on macrophytes in a Black Water River ecosystem of Enyong River in Itu and Ibiono Local Government Areas of Akwa Ibom and Cross Rivers States, Nigeria. Four vegetation plots were chosen and in each of the plots, four belt transect were laid. In each transect, macrophyte were systematically sampled in four 10 m × 10 m quadrat at regular intervals. Macrophytes were identified to species level and their frequency and density determined. Water samples were obtained in each quadrat where the macrophytes were sampled and analyzed for their physicochemical properties using standardized methods. Altogether, 10 macrophyte species were encountered. *Vossia cuspidata* had the highest density (100.00±8.00 st/ha) and frequency values (100 %). *Sacciolepis africana* had the least density of 7.10±0.45 st/ha while *Ludwigia octovalvis*, *Persicaria senegalensis*, and *Sacciolepis africana* had the least frequency of 25 %, respectively. The pH of the water was strongly acidic (5.54±0.03), electrical conductivity was low (20.00±5.77 µs/cm), temperature (29.00±1.10 ℃), Dissolved Oxygen (DO) (9.20±0.12 mg/l) and turbidity (7.10±0.06 NTU) values were high while Biological Oxygen Demand (BOD) (2.00±0.29 mg/l) Total Dissolved Solids (TDS) (10.00±0.29 mg/l) and Total Suspended Solids (TSS) were low (5.00±1.15 mg/l). Water Nutrients followed this decreasing order; chloride (3.55±0.02 mg/l) > nitrate (2.45±0.03 mg/l) > sulphate (2.02±0.06 mg/l) > phosphate (0.08±0.01 mg/l) and sulphide (0.03±0.02 mg/l). Heavy metals also followed this descending order; Pb (0.50±0.03 mg/l) > Zn (0.07±0.02 mg/l) > Cu (0.03±0.02 mg/l). Canonical Correspondence Analysis delineated 11 hydrological variables (temperature, pH, sulphate, turbidity, phosphate, BOD, nitrate, DO, TDS, sulphide and TSS) which exerted great influence on macrophyte distribution. *V. cuspidata* had affinity to pH and temperature, *Sacciolepis africana* had affinity to turbidity and BOD, *Ludwigia octovalvis* and *Nymphaea lotus* had affinity to sulphate and chloride, respectively, while *Ipomoea aquatica* and *Alternanthera sessils* had affinity to phosphate. On the other hand, *Persicaria senegalensis*, *Salvinia molesta*, *Azolla pinnata* and *Ceratophyllum demersum* had affinities to sulphide, DO, TSS and TDS, respectively. Since hydrological variables regulate macrophyte diversity and distribution, this study calls for consistent, monitoring and management of this ecosystem against future environmental changes.

Macrophytes are important components of many aquatic ecosystems. Their roles in these ecosystems cannot be overlooked as they provide numerous ecological functions such as being primary producers along food chains, providing shelter for periphyton, algae, zooplankton and assisting in nutrient cycling (Hatton-Ellis *et al*., 2003; Lacoul and Freedman, 2006). Some of them are directly involved in provision of biomass and building materials (Egertson *et al*., 2004, Bornette and Puijalon, 2011). Based on their importance, their sustainability is very pivotal in aquatic ecosystem. Be that as it may, for this to be achieved, there is need to study the intricate relationships between these plants and the environment. Macrophytes are very sensitive to the environmental conditions which they inhabit and these influence and exert great impacts on their establishments, proliferations and developments (Baattrup-Pedersen and Riis, 1999; Lacoul and Freedman, 2006). These environmental conditions include sediments, water and air. In this study, the primary focus is on hydrology. The abundance and distributions of macrophytes in lotic ecosystems are not determined by just one hydrological factor but rather by constellations of complex hydrological variables. However, these hydrological variables vary across ecosystems. While Clarke and Wharton (2001), Schneider and Melzer (2004), Baldy *et al*. (2007) stressed on nutrients as being influential on macrophyte distribution, others cited various chemicals present in the water (Mosisch and Arthington, 1998; Samecka-Cymerman and Kempers, 2007). In addition, Baattrup-Pedersen *et al*. (2006) expressed concerns over anthropogenic perturbations

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impeding the establishments of pristine macrophyte communities. These disturbances are expressed in the form of eutrophication, water pollution, changes in hydrological regime due to dams and channels construction and decline in weeds as a consequence of cutting (Baattrup-Pedersen *et al*., 2003; Daniel *et al*., 2005; Hilton *et al*., 2006 and Catford *et al*., 2011). The importance of these hydrological variables on macrophytes are strong because they are the major forces responsible for structuring macrophyte communities (De Wilde *et al*., 2016; Riera *et al*., 2017). Different types of macrophyte (e.g., emergent, rooted submerged, and free-floating) utilize environmental resources (nutrients and light) in specific ways and they also differ in their response to environmental changes (Akasaka and Takamura, 2011; Netten *et al*., 2011). For example, while submerged plants are strongly dependent on under-water light (Luhtala *et al*., 2017), free-floating plants have primacy in obtaining this resource (Lacoul and Freedman, 2006), but are more affected by availability of nutrients in the water column (Giblin *et al*., 2014). In contrast, emergent macrophytes in their early developmental stages are influenced by light availability and they obtain nutrients from sediment, being expected as less dependent on water quality than other life forms (Akasaka *et al*., 2010; Akasaka and Takamura, 2011). Nevertheless, Partanen *et al*. (2009) reported that changes in water quality can directly or indirectly affect emergent macrophytes through sedimentation of organic matter. Despite the underlining importance of hydrological variables on macrophyte distribution, very few researches have been carried out on the influence of water variables on macrophyte composition as well as the affinity each species has with hydrological variables. This being that, vast studies on macrophytes have only centered on the pedological profile as being influential on their distribution. In this ecosystem, only studies relating to water qualities and macrophyte diversity have been documented, hence, information on which water variables affect or regulate macrophyte abundance and distribution are scarce. Also, it is worthy of note that this ecosystem has areas with white and black waters, with more luxuriant macrophytes in the black water. This, however, is mind-boggling, and therefore necessitates a qualitative assessment of the black water and the affinity of each species to these water variables. Our aim is to delineate the main hydrological determinants of individual macrophytes of Enyong River in Itu and Ibiono Local Government Areas of Akwa Ibom and Cross Rivers States, Nigeria.

MATERIALS AND METHODS

Study Area: This study was carried out in a Black Water area (Latitude 5º 19' 55" N and Longitude 7º 55'56" E) of Enyong River. Enyong River lies between Itu and Ibiono Local Government Areas both in Akwa Ibom State as well as the western parts of Cross Rivers State. Enyong River lies within latitudes 5º 25' and 5º 10 N and longitudes 8º 10'and 7º 35 E. The area is well represented by structurally controlled ridges, denudation hills, extensive wetlands and alluvial plains forming soil covers of silty clay, sandy and heavily weathered loamy and alluvium. The area enjoys tropical climate and the temperature ranges from 26 to 32º C. The fluctuations in temperature are fairly uniform in character, except during the dry months when the rise in temperature is higher than it is during the long wet period (eight months-March to October) and the level of humidity is high (84%) due to close proximity to the main Cross River Channel. The average annual rainfall in the basin is 2200 mm with maximum contribution from southwest tropical maritime air-mass.

Macrophyte Sampling and Water Sampling: In this study, four vegetation plots were used. In each of the plots, four belt transects were laid and in each transect, macrophytes were sampled systematically using four 10 m × 10 m quadrats spaced at regular intervals of 20 m. In each quadrat, the density and frequency of the macrophytes were enumerated. In each quadrat where the macrophyte species occurred, water samples were also collected, stored in labelled sampling bottles, and taken to the laboratory for their physicochemical analysis.

Determination of Quantitative Variables: Density: The density of each macrophyte species was estimated by enumerating all plants present in each plot. The number of individuals of a species was taken as a proportion of the number of transects to give a mean of species. The mean was then taken as a proportion of the area of the quadrat to give density in m^2 which was multiplied by 10,000 m^2 to give density per hectare

Frequency: The frequency of each macrophyte was calculated thus;

$$F = \frac{Q_{a\,species}}{Q_{total\,species}} \times 100$$

Where F = frequency; $Q_{a\,species}$ = number of occupied quadrant for a species; $Q_{total\,species}$ = Total number of quadrants thrown

Physicochemical Analysis of Water: Electrical conductivity, Temperature, pH, and total dissolved solids were measured *in-situ* using a portable EC/temperature/pH / TDS / combined HANNA, HI 991301 model instrument. The probe was immersed in

the water to the indicated mark, and the reading as displayed on the screen was read off directly. An oxygen meter of the model Hanna H198186 was used for measuring dissolved oxygen by dipping the electrode into the water and the reading noted for a stable value. Biochemical oxygen demand (BOD) was determined by conventional method according to Association of Official Analytical Chemists (AOAC, 2000). Total suspended solids was obtained by the filtration method according to APHA (2005). The turbidity of the water was determined with the use of portable turbidity meter from Hanna instruments, HI 98703. Sulphide, Chloride, nitrate, sulphate and phosphate were determined using iodimetry method, Argentometric titration, spectrophotometric method, turbidimetric method, and colorimetry method, respectively, as outlined by APHA (2005). Pb, Zn and Cu were determined using The Inductively Coupled Plasma Optical Emission Spectrophotometry (ICP-OES 720).

Statistical Data Analysis: Means and standard errors of triplicates were computed using Graphpad Prism (6.0). Canonical Correspondence Analysis was performed using Paleontological Statistics (PAST 3.0).

RESULTS AND DISCUSSION

Compendium of the Extant Macrophyte Species: The compendium of the macrophytes in the ecosystem is presented in Table 1. A total of ten macrophyte species belonging to 9 distinct families were encountered. *Vossia cuspidata* had the highest frequency (100 %) and density (100.00±8.00 st/ha). *Ludwigia octovalvis* (25 %), *Persicaria senegalensis* (25 %) and *Sacciolepis africana* (25 %) had the least frequency while *Sacciolepis africana* had the least density of 7.10±0.45 st/ha. The percentage composition in terms of the habit of the macrophytes followed this decreasing trend; emergent (50 %) > floating-leaved (30 %) > free floating (1 %) and submerged (1 %).

Physicochemical Characterization of the Water: The physicochemical properties of the water is presented

in Table 2. The pH of the water was strongly acidic (5.54±0.03) while electrical conductivity, temperature, turbidity, total dissolved solids and total suspended solids had values of 20.00±5.77 µs/cm, 29.00±1.10 ℃, 7.10±0.06 NTU, 10.00±0.29 mg/l and 5.00±1.15 mg/l. Dissolved oxygen was high (9.20±0.12 mg/l) while Biochemical Oxygen Demand was low (2.00±0.29 mg/l). Chloride, nitrate, sulphate, phosphate and sulphide recorded mean values of 3.55±0.02 mg/l, 2.45±0.03 mg/l, 2.02±0.06 mg/l, 0.08±0.01 mg/l and 0.03±0.02 mg/l. The heavy metals followed this decreasing trend; Pb (0.50±0.03 mg/l) > Zn (0.07±0.02 mg/l) > Cu (0.03±0.02 mg/l).

Influence of Water Variables on Macrophyte Distribution: The influence of hydrological variables on the occurrence and distribution of macrophyte species was established using Canonical Correspondence Analysis (CCA). The CCA ordination of macrophytes to hydrological variables is shown in Figure 1 while the eigen values and the percentage variances of the main axes are presented in Table 3. This was carried out using the density values of the macrophytes across the various sampled plots. From the result, the CCA ordination of the first two (2) canonical axes accounted for 100 % of the total variance in the data set. Information on the variations in macrophyte distribution along hydrological gradients are borne by these axes. The cumulative percentage of the first two axes explained 100 % of the total variance (Table 3). In the triplot, small thick circles represent the macrophyte species while the arrow lines represent the water variables (vectors) for which the species had affinity for. The length of the lines is relational to the magnitude of change due to hydrological variables while the direction of the lines show their axis correlation. Longer lines show high influence of hydrological variables on the establishment of macrophytes while shorter lines indicate a low influence of these variables on the macrophytes' establishment. The distance of a named species from the vector lines entails its preference or affinity to the vector.

Table 1: Compendium of the Extant Macrophyte Species

Species	Family	Habit	Frequency (%)	Density (st/ha)
Alternanthera sessils (L.) R.Br. *ex* DC.	Amaranthaceae	Emergent	50	12.00±1.32
Azolla pinnata R. Br.	Salviniaceae	Free floating	75	59.10±4.62
Ceratophyllum demersum L.	Ceratophyllaceae	Submerged	50	13.50±1.50
Ipomoea aquatica Forssk.	Convolvulaceae	Floating-leaved	75	70.51±5.63
Ludwigia octovalvis (Jacq.) P.H. Raven	Onagraceae	Emergent	25	9.70±0.62
Nymphaea lotus L.	Nymphaeaceae	Floating-leaved	50	15.50±1.49
Persicaria senegalensis (Meisn.) Soják	Polygonaceae	Emergent	25	15.00±1.50
Sacciolepis africana C.E. Hubb. & Snowden	Poaceae	Emergent	25	7.10±0.45
Salvinia molesta D. Mitch.	Salviniaceae	Floating-leaved	75	61.50±4.12
Vossia cuspidata (Roxb.) Griffith.	Poaceae	Emergent	100	100.00±8.00

± Standard error

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The floristic anthology of the black water ecosystem showed various types of macrophytes (emergent, free floating, floating-leaved and submerged) occupying different niches in the ecosystem. This suggests that macrophytes rarely occur in monospecific stands but rather, they establish an easily recognizable formations and assemblages which are made up of species of various life forms. The number of macrophytes in this river is low when comparison is made with numbers reported by scholars in other lotic ecosystems. For instance, Adhishwar and Choudhary (2013) reported a total 137 macrophytes in Gogabil lake wetland, Bihar, India Rameshkumar *et al.* (2019) reported 15 macrophytes in a seasonal Tharavai wetland, south coast of India.

The low macrophyte diversity in this study may be affiliated to the heterogeneity of the ecosystem, anthropogenic perturbations and pollution (eutrophication) (Ogbemudia and Ita, 2016; Rameshkumar *et al.*, 2019). Macrophytes with high and low density values may have revealed their different regenerative abilities and adaptation levels to the prevailing environmental conditions. Macrophytes with high and low frequency values are indicative of a wide and ecological amplitudes. Species with close frequency values may insinuate high competition among taxa for environmental resources. The conspicuous dominance of *Vossia cuspidata* in this ecosystem synchronizes with the findings of Ogbemudia and Ita (2016). According to them, the presence of this macrophyte in increasing numbers is not unprecedented but rather it is very typical of most tropical wetlands. Aside from being commonly found in riverine wetlands, its efficient reproductive and better dispersal abilities may further account for its cosmopolitan nature in the ecosystem. In affirming this, Ogbemudia and Ita (2016) stressed that during the dry season where there is a receding water level, the vegetative parts of *Vossia cuspidata* quickly emerge from the enriched and exposed mud, with a fast regeneration ability to withstand the prevailing water logging conditions in the wet season.

Santamaria (2002) adds that plants with such good dispersal and regenerative abilities are likely to display phenotypic plasticity and polymorphism to environmental factors. The high ranking of emergent macrophytes above other life forms in this studies corroborates with the findings of Ghosh and Biswas (2015), Subhas *et al.* (2016). Their abundance in this ecosystem is not unconnected to the fact that they make use of all three possible states while growing – with their roots in sediment, beneath water and their photosynthetic parts in the air. This mechanism gives

them an edge over other life forms and makes them more productive.

Table 2: Physicochemical Characterization of the Water

Parameters	Value	WHO (2011)
pH	5.54±0.03	6.5-9.2
Electrical conductivity (μs/cm)	20.00±5.77	1500
Temperature (ºC)	29.00±1.1	20-30º C
Turbidity (NTU)	7.10±0.06	5
TDS (mg/l)	10.00±0.29	250
TSS (mg/l)	5.00±1.15	50
DO (mg/l)	9.20±0.12	5.0
BOD (mg/l)	2.00±0.29	10
Chloride (mg/l)	3.55±0.02	250
Nitrate (mg/l)	2.45±0.03	50
Sulphate (mg/l)	2.02±0.06	500
Phosphate (mg/l)	0.08±0.01	5
Sulphide (mg/l)	0.03±0.02	
Pb (mg/l)	0.50±0.03	0.01
Zn (mg/l)	0.07±0.02	5.00
Cu (mg/l)	*0.03±0.02*	*2*

± Standard error

Table 3: Eigenvalues, species–environment correlation coeffiients, and cumulative percentage for the first two axes

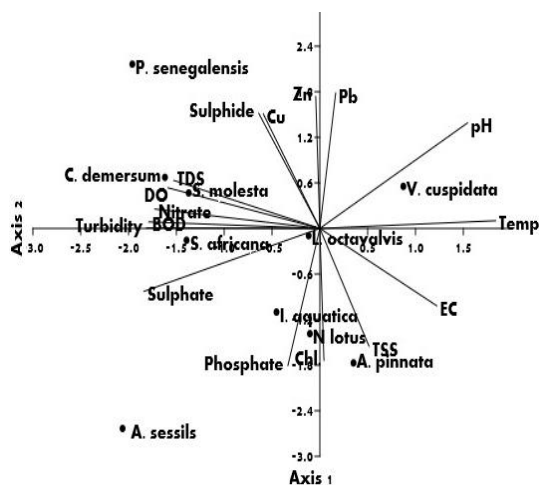| Axis	Eigenvalue	Variance explained	Cumulative Variance
1	0.048711	62.12	62.18
2	0.029709	37.88	100

Fig 1: Canonical Correspondence Analysis for water-macrophyte variables

The strongly acidic pH might have been due to high decomposition of organic matter rich in acidified substances (humic and fulvic acids). The low electrical conductivity value in this study was expected as this is a fresh water ecosystem. Turbidity was above the WHO permissible limit and this may be attributed to the ecosystem which was a black water and high intrusion of allochthonous substances (suspended and colloidal matters) into the water (Akpan, 2004). Total dissolved solids and total suspended solids were below their permissible limits. This may be attributed to low inputs of substances rich in these solids in the

ecosystem. High dissolved oxygen in this study may be linked to high photosynthetic activities by green plants which release oxygen into the water (Aguigwo, 1998; Ekpo *et al.*, 2012; Kotadiya and Acharya, 2014). Essien-Ibok *et al.* (2010) also linked high dissolved oxygen to increased flow that enabled diffusion and mixing of atmospheric oxygen into the water, as opposed to stagnation and increased organic load (mainly as leaf litter) into the water whose decomposition increase oxygen depletion. The low BOD levels in the water is suggestive of low intrusion and decomposition of organic wastes in the water. Low levels of chloride, nitrate, sulphate, phosphate and sulphide accentuate low nutrient inputs from runoffs of agricultural and domestic effluent into the water. The high ranking of Pb among the heavy metals is indicative of intense anthropogenic disturbances. According to Ter Braak (1988) and Ita *et al.* (2019), the adoption of Canonical Correspondence Analysis reveals patterns of species assemblages in response to environmental factors. This is visible in this study. The hydrological variables that were very influential on the distribution of macrophytes in this ecosystem were; temperature, pH, sulphate, turbidity, phosphate, Biochemical Oxygen Demand, nitrate, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), sulphide and Total Suspended Solids (TSS). *V. cuspidata* had great affinity to pH and temperature of the water. This may entail that these parameters were optimal for its growth and proliferations in the ecosystem. The importance of these variables to plant growth cannot be overlooked. For instance, Wrona *et al.* (2006) and Meis *et al.* (2009) asserted that temperature regulates flowering, phenology, uptake of nutrients and metabolic activities (respiration and photosynthesis). Riis *et al.* (2012) also reported that temperature favours the growth enhancement of certain macrophytes in terms of height, length of shoot, biomass production and surface area of leaf. The profuse dominance of *V. cuspidata* with affinity to temperature in this ecosystem validate the findings of Rothausler *et al.* (2011) and Riis *et al.* (2012) that emergent macrophytes under increased temperature, will become more abundant as the reproductive capacity (sporophyte growth and spore production) will be enhanced. The bonding of this species to pH may further confirm the influence of climatic factor on growth of macrophytes. pH on the other hand has been reported to be the determinant of the productivity of a site and in the segregation of plant groups (Dong *et al.*, 2014; Ita *et al.*, 2019). This is quite true at it regulates the availability of nutrients required by plants. The affinities of *L. octovalvis* to sulphate, *N. lotus* to chloride, *I. aquatica* and *A. sessils* to phosphate may highlight the water nutrient demands of these macrophytes for growth and development. Nutrients are very vital for the growth of macrophytes. Frankouich *et al.* (2006) in affirming this reported that the growth and distribution macrophytes are allied with nutrient rich environments. Hence, the essentiality of the aforementioned nutrients to macrophytes cannot be underestimated. For instance, chloride has been reported to play important roles in photosynthesis, disease suppression, osmotic and stomatal adjustment (Chen *et al.*, 2010). Sulphur taken up in the form of sulphate by plants plays critical role in protein, chlorophyll and amino acids syntheses (Jamal *et al.*, 2010). Phosphorus which is taken as phosphate by plants, plays crucial functions in being the constituent of ATP, RNA and DNA (Brown and Weselby, 2010). The preference of *P. senegalensis* to salt-rich site may accentuate its affinity to sulphide. The bonding of *S. molesta* to dissolved oxygen may point to the fact that this macrophyte thrived well in sites devoid of pollution. The affinity of *S. africana* to turbidity and Biological Oxygen Demand may expound its preference to sites that are murky and polluted with organic wastes. It may also portray its tolerance to pollution. The segregation and bonding of *A. pinnata* and *C. demersum* to Total Suspended Solids and Total Dissolved Solids may also underline their preference to hazy and less transparent sites in the water brought about by decaying substances, suspension of silt, clay inorganic and organic materials.

Conclusion: This study revealed that the occurrence and assemblages of macrophytes in various lifeforms in this ecosystem are regulated and influenced greatly by multi-hydrological variables. The affinities of macrophytes to hydrological variables and revealed their preferences and segregations to sites where these variables are highly influential in the ecosystem. From this, we conclude that hydrological factors are important drivers of macrophyte communities with regards to their climatic and nutrient requirements spatially.

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